

SUSY SEARCHES AT LEP

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Between 1995–2000, the LEP e^+e^- collider has been operated above the Z^0 peak, at centre-of-mass energies $\sqrt{s} = 130\text{--}209$ GeV. Searches for supersymmetric particles have been performed using these data samples. The results from the four LEP experiments have been combined. Model independent limits on the pair-production cross-sections of supersymmetric particles and constraints on their masses are presented in the context of the Minimal Supersymmetric Standard Model (MSSM) and in the context of gauge-mediated supersymmetry breaking models (GMSB). Results assuming an R -parity violating scenario are also reviewed.

1 Introduction

Between 1995–2000, the LEP e^+e^- collider has been operated at centre-of-mass energies $\sqrt{s} = 130\text{--}209$ GeV. The total integrated luminosity collected at these energies by each of the four LEP experiments, ALEPH, DELPHI, L3 and OPAL, is about 700 pb^{-1} .

All results described here constitute a representative selection of the combination of results from the four LEP experiments. These “LEP combinations” are preliminary and a full description can be found in¹. In most of the searches, some candidates are selected by the analyses but their number is compatible with the expected background from Standard Model (SM) processes. Since no significant excesses with respect to the Standard Model background were observed, 95% confidence level (C.L.) upper limits on the production cross-section were computed and mass limits were derived.

2 Searches for SUSY Particles in the MSSM framework

In SUSY models, each particle is accompanied by a supersymmetric partner whose spin differs by half a unit. It is often assumed that R -parity ($R \equiv (-1)^{2S+3B+L}$) is conserved and that the lightest neutralino, $\tilde{\chi}_1^0$, is the lightest supersymmetric particle (LSP). R -parity conservation implies that

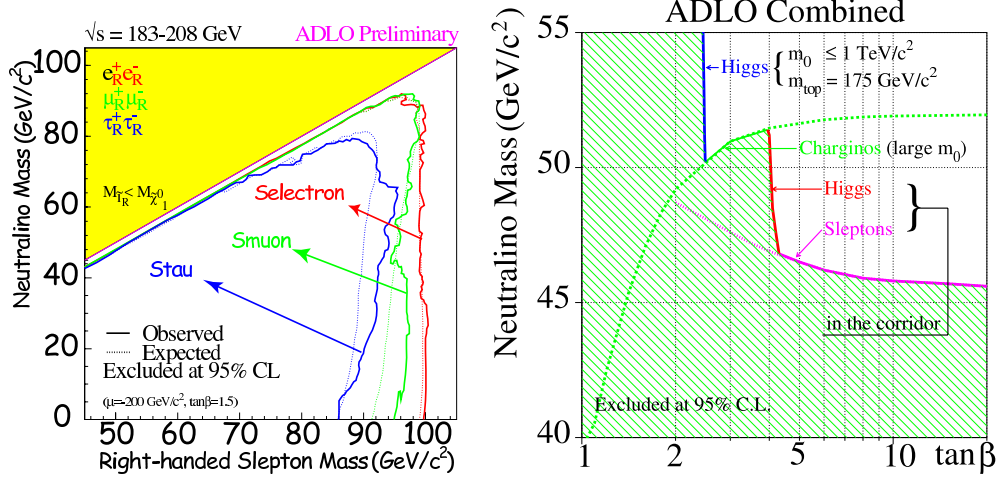


Figure 1: Left plot: 95% C.L. exclusion regions (solid lines) for pair-produced right-handed selectrons, smuons and staus as a function of the $\tilde{\chi}_1^0$ mass. For the selectron case, $\tan \beta = 1.5$ and $\mu = -200$ GeV are used. The dotted line represents the expected limits. Right plot: 95% C.L. $\tilde{\chi}_1^0$ mass lower limit as a function of $\tan \beta$.

SUSY particles are always pair-produced and always decay, through cascade decays, to ordinary particles and $\tilde{\chi}_1^0$. Moreover the $\tilde{\chi}_1^0$ is stable and escapes detection due to its weakly interacting nature. A characteristic signature of all events containing SUSY particles is therefore missing energy and momentum.

Each lepton has two scalar partners, the right and left-handed charged scalar leptons (sleptons), denoted $\tilde{\ell}_R$ and $\tilde{\ell}_L$, according to their helicity states. The dominant slepton decay mode is: $\tilde{\ell}^\pm \rightarrow \ell^\pm + \tilde{\chi}_1^0$. The event topologies are two acoplanar leptons and missing energy.

Exclusion regions for pair-produced right-handed selectrons, smuons and staus are shown in Fig. 1 (left plot). A right-handed selectron with a mass smaller than 99.6 GeV, a right-handed smuon with a mass smaller than 94.6 GeV and right-handed stau with a mass smaller than 85.9 GeV are excluded.

Searches for scalar top and bottom quarks (stop and sbottom) were also performed. Because of the large mass splitting by left-right mixing, $\tilde{t}_1 = \tilde{t}_L \cos \theta_{mix} + \tilde{t}_R \sin \theta_{mix}$, the lowest mass eigenstate, \tilde{t}_1 , could be the lightest charged supersymmetric particle. The stop quark pair-production cross-section depends on the stop mass, $m_{\tilde{t}_1}$, and the mixing angle θ_{mix} . If the stop quark is assumed to be lighter than every other charged sparticle, the dominant decay mode is the 2-body flavour changing decay $\tilde{t}_1 \rightarrow c + \tilde{\chi}_1^0$. The event topologies would therefore be two acoplanar jets with missing energy. For $\theta_{mix} = 56^\circ$ and assuming the 2-body decay, a stop with a mass smaller than 95 GeV is excluded. For large $\tan \beta$, there could be a large mixing also between the right- and left-handed \tilde{b} quarks, resulting in two states, \tilde{b}_1 and \tilde{b}_2 . The lowest lying state, \tilde{b}_1 would decay primarily to $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$ leading to a topology identical to the pair-production of stop quarks followed by 2-body decay. For $\theta_{mix} = 68^\circ$, a sbottom with a mass smaller than 94 GeV is excluded.

The charginos, $\tilde{\chi}_{1,2}^\pm$, could be pair-produced at LEP either through γ or Z^0 exchange in the s -channel or through sneutrino exchange in the t -channel. The production cross-section could be fairly large and therefore the search for charginos was one of the most appealing SUSY searches. The $\tilde{\chi}_1^\pm$ could decay into a $\tilde{\chi}_1^0$ and an ordinary lepton: $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 l^\pm \nu$ (leptonic decay), or into a neutralino and a quark pair: $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 q \bar{q}'$ (hadronic decay) through a virtual W^* , slepton or scalar quark emission. The experimental signature for $\tilde{\chi}_1^\pm$ production is therefore: a) two acoplanar leptons, b) one lepton plus jets or c) multi-jets; all these topologies share the characteristic of a large missing energy carried away by the neutralinos. The most challenging

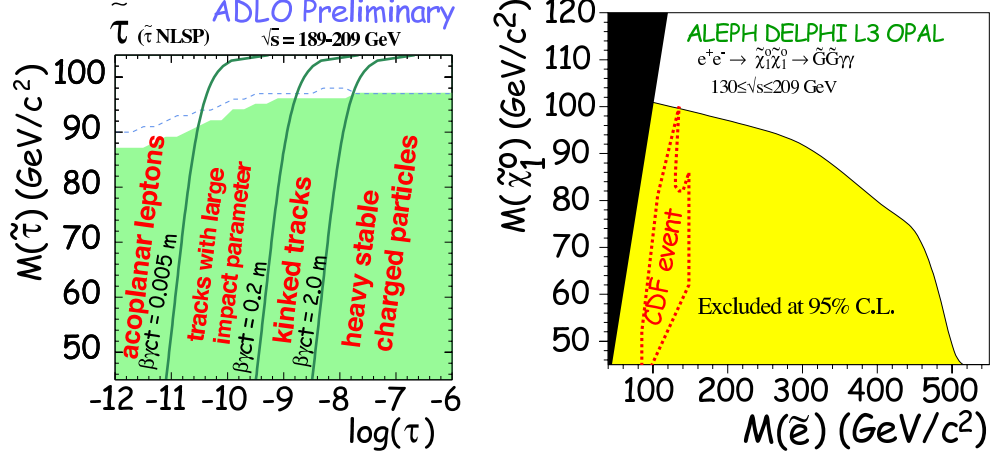


Figure 2: Left plot: 95% C.L. excluded mass regions for right-handed staus (NLSP) as a function of the NLSP lifetime combining four different searches. Right plot: 95% C.L. excluded region in the $(m_{\tilde{e}_R}, m_{\tilde{\chi}_1^0})$ mass plane assuming a $\tilde{\chi}_1^0$ NLSP; this limit is derived from the search for acoplanar photons assuming a zero lifetime NLSP.

search is when the mass difference between the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ ($\Delta m = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$) is small, because the event visible energy also becomes very small. Detailed searches for charginos in the small Δm region have been performed. In the case of a very small mass difference ($\Delta m \leq 0.1$ GeV), the charginos would be quasi-stable charged particles. The searches are based on the specific ionisation loss measurement, dE/dx , provided by the central detectors of each experiment. No evidence for chargino production has been observed by the four LEP collaborations in any of the Δm regions. The 95% C.L. lower limits on the $\tilde{\chi}_1^\pm$ mass obtained for the case of a heavy sneutrino and $\Delta m \geq 10$ GeV are close to the kinematic limit.

The neutralinos could be pair-produced through s -channel virtual Z^0 exchange or t -channel scalar electron exchange. Alternatively one can look directly for the production of a $\tilde{\chi}_2^0 \tilde{\chi}_1^0$ pair. The $\tilde{\chi}_2^0$ could then decay into $\tilde{\chi}_1^0 l^+ l^-$, $\tilde{\chi}_1^0 \nu \bar{\nu}$ or $\tilde{\chi}_1^0 q \bar{q}$, through a virtual Z^0 , Higgs boson, slepton or squark exchange. The event topologies are similar to those studied for $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ events.

From these studies, a 95% C.L. lower mass limit of $m_{\tilde{\chi}_1^0} > 46$ GeV was derived for any value of $\tan \beta$ (right plot of Fig. 1). Since the LSP could be a good candidate for dark matter, this lower mass bound is interesting also from a cosmological point of view.

3 Searches for Gauge Mediated Supersymmetry Breaking (GMSB) Signatures

In the GMSB framework, supersymmetry is broken via the usual gauge interactions in a hidden sector, which couples to the visible sector of the Standard Model and SUSY particles via a messenger sector. The supersymmetric partner of the graviton, the gravitino \tilde{G} is assumed to be the LSP, and the next-to-LSP (NLSP) could either be the lightest neutralino, $\tilde{\chi}_1^0$, or a right-handed slepton, \tilde{l}_R . The NLSP decay length is unconstrained and all possible decay lengths between zero and infinity had to be considered, suggesting to explore many different final state topologies. Fig. 2 (left plot) shows the 95% C.L. excluded $\tilde{\tau}_R$ mass as a function of the lifetime, assuming a $\tilde{\tau}_R$ NLSP and combining searches exploring various regions of the NLSP lifetime. The very short lifetime range is covered by the search for events with a pair of acoplanar leptons; the intermediate lifetime range is covered by the searches for events containing tracks with large impact parameters and kinks; and the long lifetime range is covered by the search for heavy stable charged particles. Fig. 2 (right plot) shows the 95% C.L. excluded region in the $(\tilde{e}_R, \tilde{\chi}_1^0)$ mass plane assuming a $\tilde{\chi}_1^0$ NLSP; this limit is derived from the search for events with acoplanar

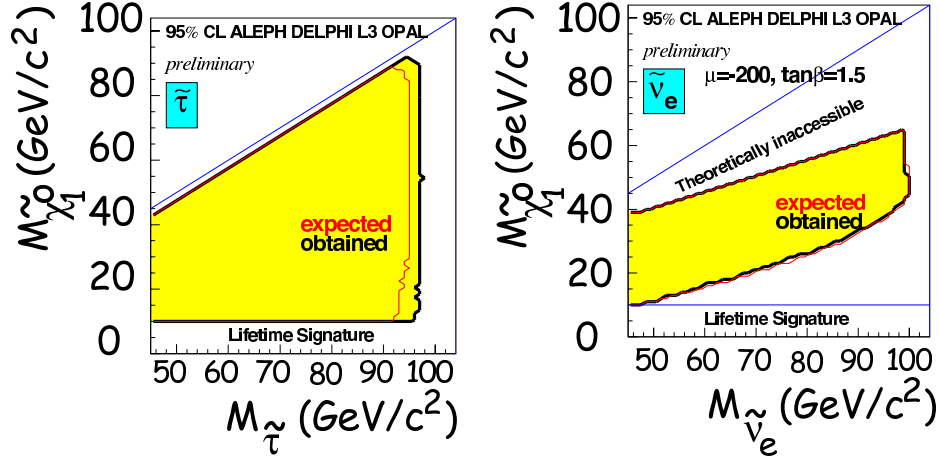


Figure 3: 95% C.L. lower mass limits for a right-handed selectron (left plot) and for a sneutrino (right plot). The exclusions are shown for a λ coupling and for $\tan \beta = 1.5$ and $\mu = -200$ GeV.

photons and assuming a zero lifetime NLSP.

4 Searches for R -parity Violation Decays of Supersymmetric Particles

If R -parity is violated, the sparticles could decay directly to Standard Model particles and any sparticle could be the LSP. The topologies differ significantly from the ones with conserved R -parity.

With the MSSM particle content, R -parity violating interactions are parametrised with a gauge-invariant super-potential that includes the following Yukawa coupling terms:

$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k, \quad (1)$$

where i, j, k are the generation indices of the super-fields L, Q, E, D and U . L and Q are respectively the lepton and quark left-handed doublets. \bar{E} , \bar{D} and \bar{U} are respectively the right-handed singlet charge-conjugate super-fields for the charged leptons and down- and up-type quarks. This makes a total of 45 parameters in addition to those of the R -parity conserving MSSM.

The left plot of Fig. 3 shows the 95% C.L. lower mass limits for right-handed pair-produced staus while the right plot shows the 95% C.L. limits for pair-produced sneutrinos. The exclusions are shown for a λ coupling and for $\tan \beta = 1.5$ and $\mu = -200$ GeV.

5 Conclusions

LEP has been a great success until its very end allowing a multitude of searches for new particles. These searches have been performed using a total integrated luminosity of about 700 pb^{-1} per experiment, at centre-of-mass energies up to 209 GeV. A number of preliminary combinations of these searches for new particles have been performed and interpreted in various models. No significant evidence for new physics is observed. Very stringent 95 % C.L. limits on cross-sections and sparticle masses have been computed.

References

1. <http://lepsusy.web.cern.ch/lepsusy>.